Biogas Production from Food Waste and Vegetable Waste for the Sakaew Temple Community Angthong Province Thailand

K. Hussaro, J. Intanin, and S. Teekasap

Abstract— *The experimental co-digestion of biogas production of typical food waste with vegetable waste and chicken dung from the Sakaew Temple Community, Angthong Provice, Thailand, in order to identify the optimization condition that determine the amount of biogas and methane content. The process in this research were consisted of 4 methods, which were the survey of food waste to the community, design and set up biogas production system, fermentation experiment to find the optimum condition, and technology transfer to the community. Biogas production was operated in 200 L of digester for 40 days. During this research process, the materials for biogas process were mixed in the 5 different ratios of food waste with vegetable waste : chicken dung as follows; 1 : 1 (Digester D3), 2 : 1 (Digester D4) , 3 : 1 (Digester D5), 1:0 (Digester D1), and 0 : 1 (Digester D2). From this result, it was found that the ratio of food waste to the chicken dung, 1:1 (Digester D3) was provided the highest amount of biogas, which was 18.83 kg and the highest content methane gas were 72 %. The carbon to nitrogen ratio, temperature digester, and pH at the digester D3 were 18.83, 29.8 ºC, and 6.87, respectively. After calculating the economic internal rate of return, it was found that the payback period was 16.4 days for the digester D3. The results of the satisfaction evaluation for the technology transfer to the Sakaew Temple Community, Angthong Province shown that the participants were mostly satisfied.*

Keywords— **Food waste, chicken dung, renewable energy, biogas production, Sakaew temple community.**

1. INTRODUCTION

Nowadays, the energy and environmental issues are considered as the very important issues, both in Thailand and many countries around the world. The final energy consumption was about 74,214 tons of oil equivalents in Thailand in 2013, which increasing about 2.6 % from that of in 2012. The energy consumption was 1,793 billion baht. The proportion of 81.4 % of the final energy consumption was used to the consumption energy, which remaining 7.9 % of renewable energy and 10.7 of traditional renewable energy. Therefore, 61,236 tons of oil equivalent has used to commercial energy consumption by 2013. There was increased about 1.5 % from 2012, which consist of (i) Oil has been used 35,948 tons of oil equivalent, there were increased about 3.1%, (ii) Electricity has been used 14,002 tons of oil equivalent, there were increased about 1.6 %, (iii) Coal and lignite were using 5,947 tons of oil equivalent, which were decreased about 9.6 %, and (iv) Natural gas has been used 5,339 tons of oil equivalent with increasing about 4.8 %. For renewable energy (Solar energy, coal, firewood, rice husks, bagasse, agricultural waste, waste residues, and biogas), 5,902 tons of oil equivalent has been used, there was increased about 4.7 %. Finally, Renewable energy (Charcoal, firewood and agricultural residues) has traditionally used 8,076 tons of oil equivalent, which an increasing about 10 % from 2012 [1].

Ministry of Energy has forecast the country's future energy used which needs to demand for 99,838 tons of oil equivalent in Thailand. Therefore, there are implemented a plan to develop renewable and alternative energy about 25 % in 10 years (between 2012-2021). Biogas production target was 3,600 MW for 2021 (600 MW from industrial waste and manure and 3,000 MW from Napier grass). There are widely encouraging community participation in the biogas production and use of renewable energy by encouraging the production of biogas at the household level. Especially, rural communities have receiving the benefit and support for the development of gas pipeline networks for biogas in the community.

Anaerobic digestion (AD) refers to a process where organic matter is synergistically decomposed by a microbial consortium in an oxygen free environment. AD can be used to convert organic matter into biogas for energy recovery and achieve waste stabilization and odors reduction [2]. AD can be operated under liquid (wet), semi-solid, or solid-state (dry) conditions, when the total solids (TS) of substrate are < 10%, 10-15 %, or >15 %, respectively. Largely, liquid AD is frequently applied in the full-scale operations, owing to reasons such as easy operation and maintenance, and increasing methane yield [3]. Biogas mainly composed of 50-70 % of methane, CH_4 (valorized in electricity and heating) and 50-30 % of carbon dioxide, CO_2 with traces of other impurities, such as hydrogen sulfide (H_2S), ammonia

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(NH_3), and water vapor [4].

Co-digestion of mixed substrates offers many advantages, including ecological, technological, and economic benefits as compared to a single substrate digestion. However, the combination of two or more different types of feedstock requires the careful selection to improve the efficiency of anaerobic digestion. The aim of the co-digestion is to balance nutrients (C/N ratio and macro- and micronutrients) and dilute inhibitors/toxic compounds to enhance methane production [5]. Namely, it could be improved the buffer capacity and reduced ammonia inhibition of the liquid mixture due to the better carbon and nutrient balance [6, 7]. The optimal carbon to nitrogen (C/N) ratio of 15-30 is preferred for anaerobic digestion and hence external supplementation of carbon has to be regularly performed to dilute (Total Kjeldahl Nitrogen: TKN) concentration, in order to achieve a stable and efficient process. It should be noted that the dilution can done by adding water [3].

There were many factors would influence on anaerobic co-digestion such as temperature, pH, organic loading rate, and hydraulic retention time. The pH value was the crucial importance, it could affect the activities of specific acidogenic and methanogenic bacteria, then affecting to the biogas production. The optimal pH range of anaerobic co-digestion for biogas generation was between 6 and 8 [8]. Normally, anaerobic bacteria can grow at psychrophilic (10-30 °C), mesophilic (30-40 °C), and thermophilic (50-60°C) conditions. The performance of AD was increased with an increase in temperature, stressing the advantages of the thermophilic operation with its higher metabolic rates, higher specific growth rates, and higher rates of the detruction of pathogens along with higher biogas production. However, many advantages were observed under thermophilic condition, some disadvantages are worth considering since the thermophilic process is more sensitive to environmental changes than the mesophilic process [9].

As Thailand is an agricultural country, it has enormous sources of biomass that can be used for the production of renewable energy such as agricultural residues and animal manure. Sakaew Temple Community Angthong Province has a large population of food waste, which it has become a big environmental problem. Generating large amounts of surplus animal manure can be used in biogas production to produce renewable energy. Food waste has already been considered as a very attractive feedstock for anaerobic digestion due to its high methane potential [10]. Food waste is a desirable material to co-digestion with animal manure because of its high biodegrability [11].

The aims of this study were to evaluate the potential of anaerobic co-digestion of food waste with vegetable waste and chicken dung along with the effect of mixing ratios of food waste with vegetable waste and chicken dung on amount of biogas and methane content. Another objective was to calculate an economic analysis via payback period value from optimizing digester of mixture of food waste with vegetable waste and chicken dung.

2. MATERIALS AND METHODS

2.1 Collection and Preparation of Substrates

Chicken dung was collected from a dairy farm near Sakaew Temple Community Angthong Province, Thailand during April 2016. The samples were scraped off the feed lanes and collected in 200-L buckets. The samples were transported immediately to the Sakaew Temple Community (Sakaew Temple School). Food waste with vegetable waste was collected, during April 2016, from Sakaew Temple Community Angthong Province (Sakaew Temple School) processing of average 105.28 kg/day of food waste with vegetable waste, by screening and grinding, as a feedstock for an anaerobic co-digester.

2.2 Anaerobic Co-digestion

2.2.1 Experimental design and set-up

The anaerobic co-digestion experiments were carried out on varying mixtures of food waste with vegetable waste and chicken dung in order to determine the best combination of substrates ratios for biogas production. The experiments were conducted in five identical 200 L digester reactors with 150 L working volume using water displacement. The digesters' reactors were labeled D1 (food waste with vegetable waste : chicken dung, 1:0), D2 (food waste with vegetable waste : chicken dung, 0:1), D3 (food waste with vegetable waste: chicken dung, 1:1), D4 (food waste with vegetable waste : chicken dung, 2:1), and D5 (food waste with vegetable waste : chicken dung, 1:2). The Schematic diagram for anaerobic co-digestion device is presented in Fig. 1. These mixture ratios were specified according to the amount of food waste with vegetable waste and chicken dung that could be delivered to existing Sakaew Temple School and dairy farm in Sakaew Temple Community Angthong Province where the co-digestion practice is intended. It was intended to co-digest this amount of chicken dung with either 30 and 30 kg/day of food waste with vegetable waste. These quantities of food waste can be delivered by two or three buckets respectively. The initial volume of chicken dung for the digestion of chicken dung and water were 30 kg and 70 liter, respectively. Aftter the chicken dung was mixed with the water in the ractors, food waste with vegetable waste was added to fill the volumes up to effective volumes of the follow five ratios of substrates. All the reactors were carried out in duplicate using 200-L anaerobic reactors at mesophilic temperature for 40 days.

2.2.2 Analytical Methods

Total solids (TS), volatile solids (VS), ammonia nitrogen, TKN, volatile suspended solids, suspended solids, total phosphorus (P), total nitrogen (N), chemical oxygen demand (COD), COD:N:P, carbon content, nitrogen content, and carbon to nitrogen ratio (C/N ratio) were measured in accordance with the standard methods (APHA, 1999) [12]. The pH and temperature of the substrated mixture in the digesters was measured every day by pH meter and data logger (Amron, ZR-RX25), respectively. Biogas was colleted by water displacement method. The biogas volume was calculated daily and transformed into the volume at STP condition. Biogas samples were examined by Geotech, BIOGAS 5000 to determine the CH_4 and CO_2 content.

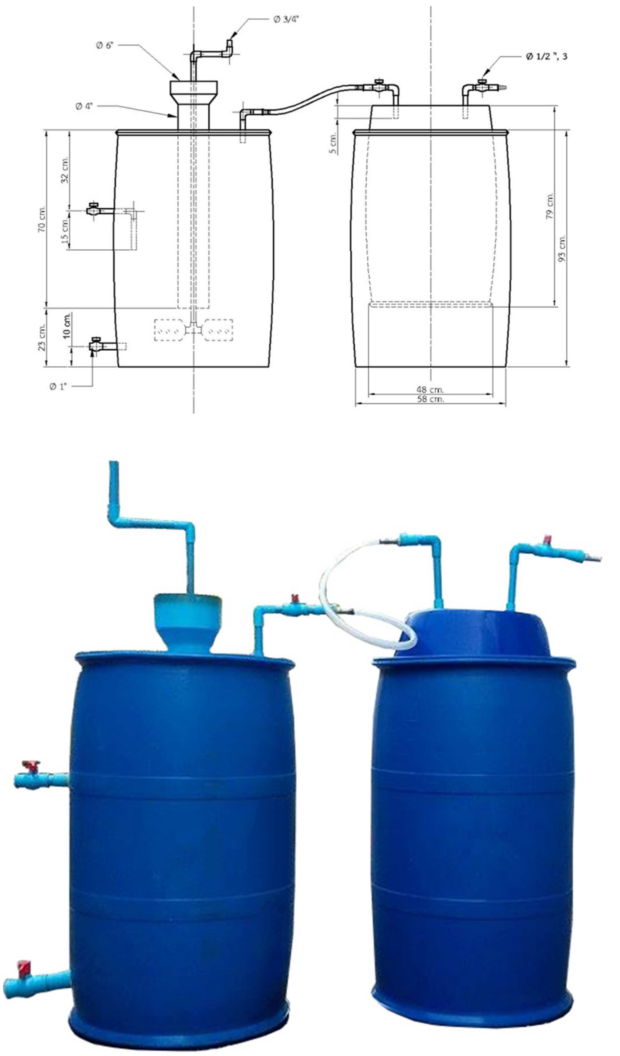

Fig. 1. The Schematic Diagram for Anaerobic Co-Digestion Device.

3. RESULTS AND DISCUSSION

The dialy record of food waste from Watsrakaew school, Angthong province for March-April 2016 is shown in Table 1. Watsrakaew School, Angthong Province, produced average and accumulates about 105.28 kg/day and 5,484.75 kg for 53 days of the food waste with vegetable waste, respectively. On the other hand, food waste is a potential organic substrate for biogas production through anaerobic digestion (AD), which 1 kg of food waste can be produced biogas 41 L [13]. Therefore, the feasibility 105.28 kg/day of food waste can be produced 4,324.27 L/day of biogas.

3.1 Characteristics of Substrates

The chemical characteristics of food waste with vegetable waste and chicken dung are shown in Table 2. It was found that, food waste contain 28,000 mg/l of chemical oxygen demand (COD), and 100:1.46:1.59 of COD/N/P ratio, which there was COD/N/P ratio more than the theory and literature reported [14]. For the decomposition of organic matter by fermentation using anaerobic conditions, independent of the biogas process. From this research shows that the food wastes had nutrients (nitrogen and phosphorus) sufficient for the growth of microorganisms.

The C/N ratio of food waste and chicken dung was 26.76 and 8.9 respectively. Food waste and chicken dung were considerably suitable for anaerobic digestion, which is consistent with other research and theory [15]. The carbon-to-nitrogen ratios for each digester that were affect the production of biogas as shown in Table 3. The results found that the ratio of carbon to nitrogen is sufficient and suitable for the production of biogas between 8.9 to 26.76.

3.2 Biogas Production from Food Waste with Vegetable Waste and Chicken Dung

Fig. 2 represents typical biogas production curves for D1 (food waste: chicken dung = 1:0), D2 (food waste: chicken dung = 0:1), D3 (food waste: chicken dung = 1:1), D4 (food waste: chicken dung = 2:1), and D5 (food waste: chicken dung = 3:1). From this figure, it can be suggested that co-digestion was easily and completely biodegradable by the population of a digester 3 to digester 5 within 9 days. While, mono digestion had a long time completely biodegradable by the population of a digester 1 to digester 2 within 14 days. The cumulative biogas production of D3, D4, D5, D1, and D2 were 2,104.7, 1,855.21, 1,607.39, 1,152.45, and 704.76 L, respectively. The addition D3 was significantly highest biogas production, indicating that the maximum metabolic capacity for the microbial population was exceeded. The carbon to nitrogen (C/N) ratio of D3 was 18.83, indicating that the maximal biogas production capacity of the population was reached, which is in agreement with the findings of the other research [16].

The optimum C/N ratio for anaerobic co-digestion to obtain higher biogas production may depend on the type of waste used as co-substrate for C/N ratio adjustment. As in the present research, highly biodegradable chicken dung with high nitrogen content (Table 2) was mixed with food waste, vegetable waste, which has comparatively low nitrogen and biodegradability.

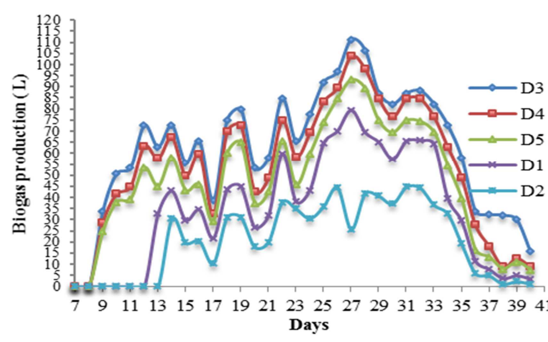

Fig.2. Comparison of Biogas Production from All Digesters; D1 (food waste: chicken dung = 1:0), D2 (food waste: chicken dung = 0:1), D3 (food waste : chicken dung = 1:1), D4 (food waste : chicken dung = 2:1), and D5 (food waste : chicken dung = 3:1).

Table 1. Amount of Food Waste with Vegetable from Sakaew Temple Community, Angthong

Day/Month/ year	Amount of food waste (kg)	Height of water (h, cm)	Volume of wet food waste (L) $V = \left(\frac{\frac{\pi}{4}}{1000}\right)D^2h$
8/3/2559	103	56	28.21
9/3/2559	114	57	28.71
10/3/2559	125	59.5	29.97
11/3/2559	117.75	59.5	29.97
12/3/2559	110.5	56	28.21
13/3/2559	109.5	57	28.71
14/3/2559	108.5	59	29.72
15/3/2559	104.75	56.5	28.46
16/3/2559	101	58	29.21
17/3/2559	96.75	59.5	29.97
18/3/2559	92.5	57	28.71
19/3/2559	102	55.5	27.95
20/3/2559	113	58	29.21
21/3/2559	97	56	28.21
22/3/2559	106	60	30.22
23/3/2559	111	57.5	28.96
24/3/2559	99	55	27.70
25/3/2559	112	58	29.21
26/3/2559	98	56.5	28.46
27/3/2559	109	59	29.72
28/3/2559	115	60.5	30.47
29/3/2559	103	53	26.69
30/3/2559	101	58	29.21
1/4/2559	110	57.5	28.96
2/4/2559	99	59.5	29.97
3/4/2559	97	58	29.21
4/4/2559	106	60.5	30.47
6/4/2559	114	61	30.72
7/4/2559	107	59.5	29.97
8/4/2559	109	55.5	27.95
9/4/2559	97	58	29.21
10/4/2559	99	56.5	28.46
11/4/2559	103	57	28.71
12/4/2559	106	59	29.72
13/4/2559	105	57.5	28.96

Table 1. Amount of Food Waste with Vegetable from Sakaew Temple Community, Angthong (Con't)

Day/Month/ year	Amount of food waste (kg)	Height of water (h, cm)	Volume of wet food waste (L) $V = \left(\frac{\frac{\pi}{4}}{1000}\right)D^2h$
14/4/2559	98	55.5	27.95
15/4/2559	99.5	58.5	29.46
16/4/2559	114	59.5	29.97
17/4/2559	111	60.5	30.47
18/4/2559	109	56	28.21
19/4/2559	97	56.5	28.46
20/4/2559	103	58	29.21
21/4/2559	99	57	28.71
22/4/2559	111	57.5	28.96
23/4/2559	98	55.5	27.95
24/4/2559	112	59	29.72
25/4/2559	106	53	26.69
26/4/2559	115	61	30.72
27/4/2559	97	53.5	26.95
28/4/2559	105	59.5	29.97
29/4/2559	108	59	29.72
30/4/2559	98	57.5	28.96
31/4/2559	106	55	27.70
Total value	5,484.75	2,997.5	1,509.74

Analysis of variance for biogas production from all digesters is reported in Fig. 3. The analysis revealed that the food waste with vegetable waste ratio and chicken dung is significantly positively correlated with biogas production, *p*-value = 0.001. Since, *p*-value is lesser than 0.05, which is concluded that the correlation coefficients are statistically significant at 99% confidence level. The calculate means value for biogas production from all digesters are presented in Fig. 3, it was found that the highest mean data from all digesters was obtained in D3 including to normal probability plot had linear.

3.3 Methane Content from Food Waste with Vegetable Waste and Chicken Dung

All the successful digesters showed the similar trends in daily methane contents, which is shown in Fig.4. It was found that the same methane production as for co-digestion (D3 to D5) was obtained in 9 days of digestion. However, methane production as for mono digestion (D1 and D2) went on at almost the same as that of 14 days. Furthermore, the quality of the generated biogas was also improved with the addition food waste with vegetable waste into the mixtures. The highest methane content of biogas was 72 % (at 27th day), 67 % (at 27th day), 59 % (at 26th day), 55 % (at 26th day) and 51 % (at 33th day) for D3, D4, D5, D1, and D2, respectively. Highest methane content in the biogas has also been observed by D3.

Table 2. The Chemical Characteristics of Food Waste with Vegetable Waste and Chicken Dung

Parameter	Food waste	Chicken dung
pH	6.8	7.1
TKN (mg/L)	1,185	256
NH_3 (mg/L)	42.7	30.5
Total solids (mg/L)	176,728	566,764
Volatile solids (mg/L)	158,231	10,050
Volatile suspended solids (mg/L)	109,210	6,900
Suspended solids (mg/L)	111,240	600,000
Total phosphorus (mg/L)	446	250.12
Total nitrogen (mg/L)	410	209
COD	28,000	-
COD:N:P	100:1.46:1.59	-
Carbon (%)	49.5	26.97
Nitrogen (%)	1.85	3.02
Carbon/Nitrogen Ratio (C/N)	26.76	8.9

Analysis of variance for methane production from all digesters is reported in Fig. 5. The analysis revealed that food waste with vegetable waste ratio and chicken dung is significantly positive correlated with methane production, *p*-value = 0.001. Since, *p*-value is lesser than 0.05, which it is suggested that the correlation coefficients are statistically significant at 99% confidence level. The calculate means for methane production from all digesters are presented in Fig. 5, it was found that the highest mean data from all digesters was obtained in D3 including to normal probability plot had linear.

3.4 Temperature in Digesters from All Digesters

The average temperature in digester of all digesters under different ratio of substrates is shown in Fig. 6. The average temperature in digester of D3, D4, D5, D1, and D2 were 29.8, 29.5, 29.3, 28.8, and 28.3 °C, respectively. The results show that the cumulative biogas production had the highest average temperature in digester. During digestion of D1 to D5 at average temperatures in the range of 28.3 to 29.8 °C, found that D3 at 29.8 °C (mesophilic) achieved the highest biogas production and methane content.

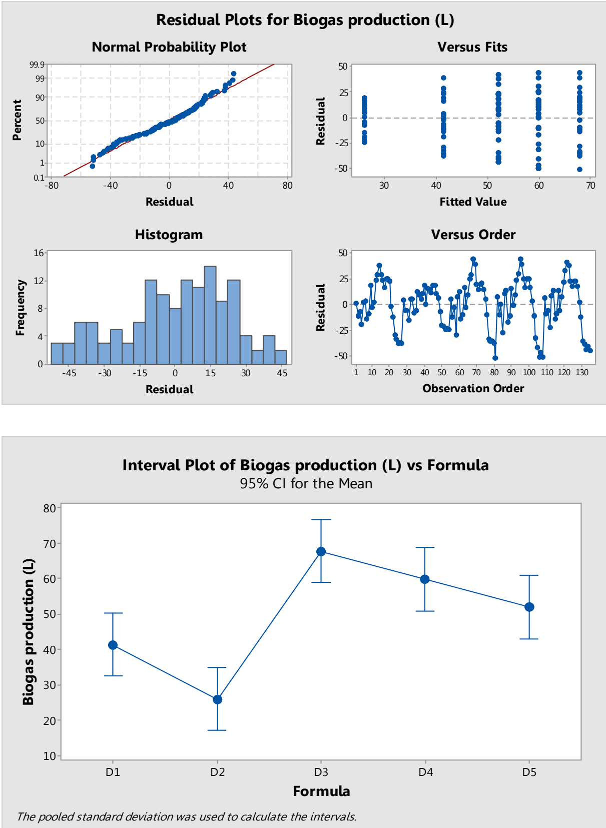

Fig.3. Analysis of Variance for Biogas Production from All Digesters.

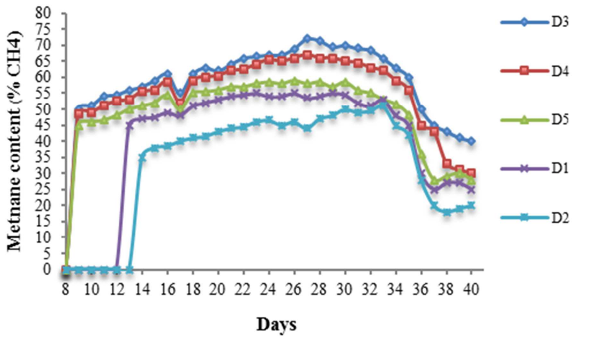

Fig.4. Methane Content from from All Digesters; D1 (food waste : chicken dung = 1:0), D2 (food waste : chicken dung = 0:1), D3 (food waste : chicken dung = 1:1), D4 (food waste : chicken dung = 2:1), and D5 (food waste : chicken dung = 3:1).

However, analysis of variance for temperature in digester from all digesters is reported in Fig. 7. The analysis revealed that food waste with vegetable waste ratio and chicken dung is significantly positively correlated with temperature in digester, p-value = 0.001. Since, *p*-value is lesser than 0.05, which it is concluded that the correlation coefficients are statistically significant at 99% confidence level. The calculate means for temperature in digester from all digesters are presented in Fig. 7, it was found that the highest mean data from all digesters was obtained in D3 including to normal probability plot had linear.

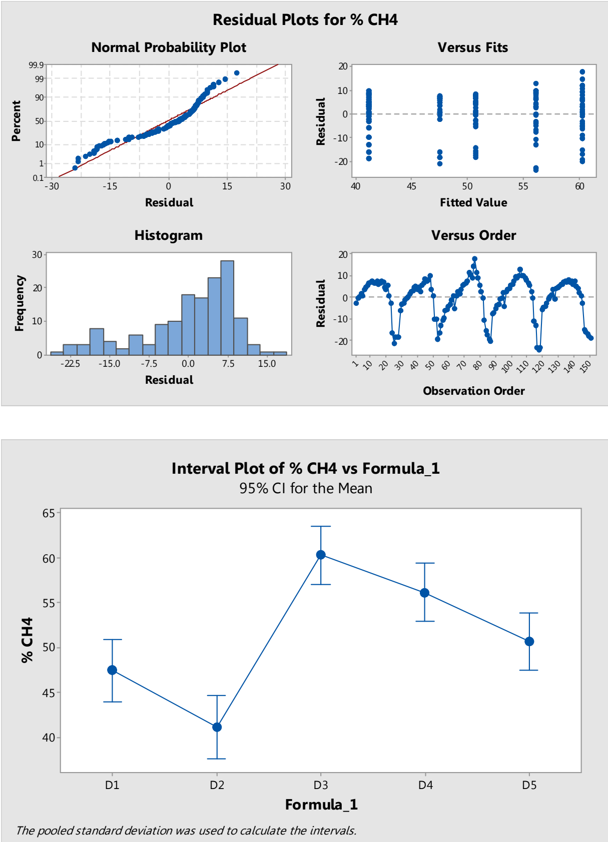

Fig.5. Analysis of Variance for Methane Production from All Digesters.

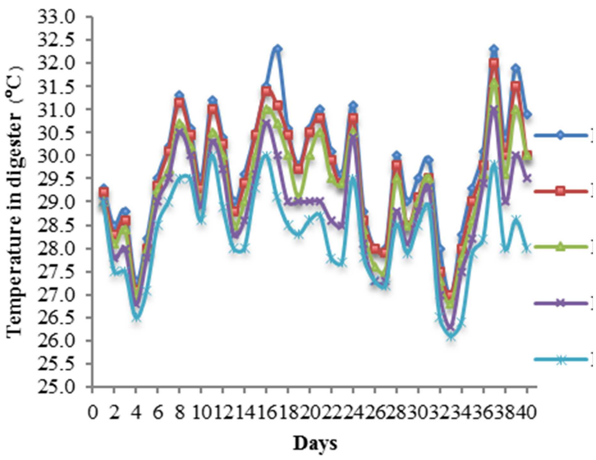

Fig.6. Temperature in Digester from All Digesters; D1 (food waste: chicken dung = 1:0), D2 (food waste: chicken dung = 0:1), D3 (food waste: chicken dung = 1:1), D4 (food waste: chicken dung = 2:1), and D5 (food waste: chicken dung = 3:1).

3.5 pH Value from All Digesters

The pH profiles of all digesters in this research are shown in Fig. 8. It was found that the pH value from D3, D4, D5, D1, and D2 was obtained and average of 6.87, 6.64, 6.52, 6.42, and 6.36, respectively. The pH value of D3 to D5 was well near 7.0 throughout the investigation. The pH value which was suitable for anaerobic digestion is range 6.5 to 8.0. If the pH value of the substrate is either lower than 6.0 or greater than 8.0, methanogens will be inhibited and volatile fatty acids will be accumulated. However, analysis of variance for pH value from all digesters is reported in Fig. 9. The analysis revealed that food waste with vegetable waste ratio and chicken dung is significantly positively correlated with pH value, *p*-value = 0.001. Since, p-value is lesser than 0.05, which is concluded that the correlation coefficients are statistically significant at 99% confidence level. The calculate means for pH value from all digesters are presented in Fig. 9, it was found that the highest mean data from all digesters was obtained in D3 including to normal probability plot had linear.

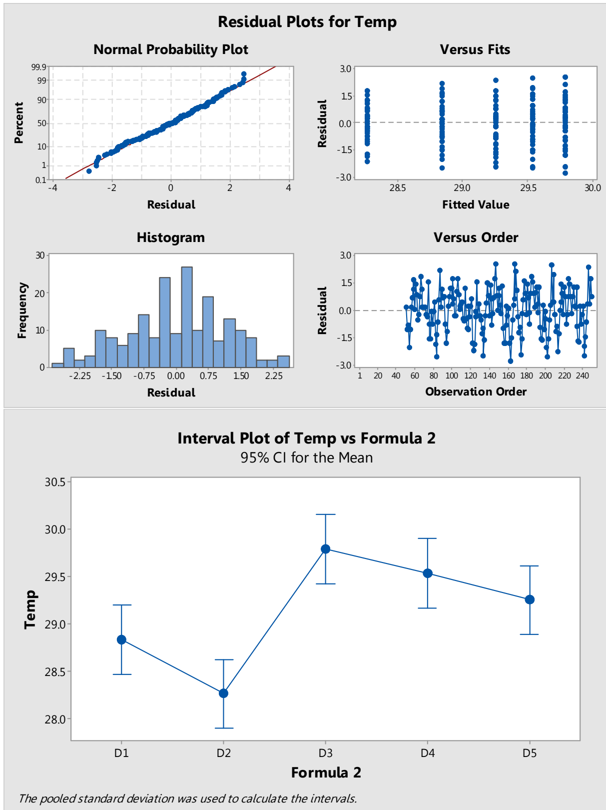

Fig.7. Analysis of Variance for Temperature in Digester from All Digester.

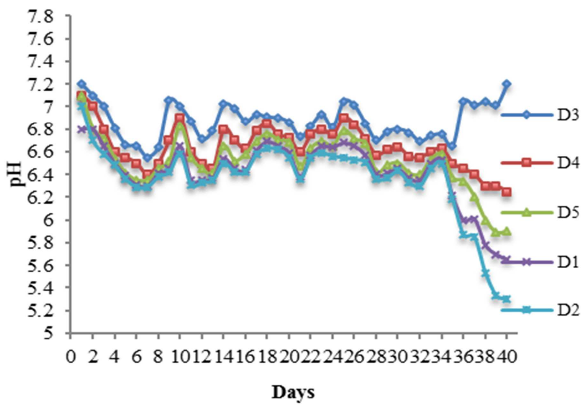

Fig.8. pH Value from All Digesters; D1 (food waste: chicken dung = 1:0), D2 (food waste: chicken dung = 0:1), D3 (food waste: chicken dung = 1:1), D4 (food waste: chicken dung = 2:1), and D5 (food waste: chicken dung = 3:1).

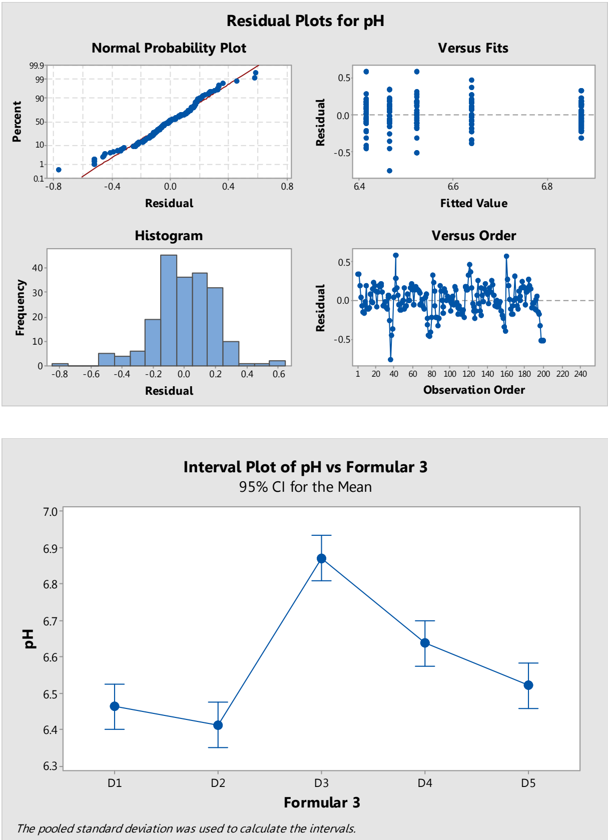

Fig.9. Analysis of Variance for pH from All Digesters.

3.6 Economic Evaluation

To investigate the economic evaluation of the suggested biogas production from D3 by calculation payback period, as following:

Payback period = Total fixedcosts/[(Capacity/day)x(LPG price)]

1 kg of LPG = 1.82 L

Total fixed costs = 5,000 Baht (including fermentation and measurement biogas system)

Capacity of biogas production/day (D3) = Cumulative biogas production/HRT

Capacity of biogas production/day (D3) = 2,107.40/38 = 55.46 L

Biogas production/day = 55.46/1.82 = 30.47 kg of LPG
LPG price in the market is not compressed in tank was 10 Baht/kg

Therefore;

Payback period = 5,000 Baht/(30.47 kg of LPG/day X 10 Baht/kg)
= 16.4 days

4. CONCLUSIONS

Anaerobic co-digestion has been shown to be a promoting strategy for utilizing food waste with vegetable waste and chicken dung for biogas production. This strategy may also be used for other agricultural waste which resists anaerobic digestion due to their acidic pH [17]. Anaerobic co-digestion of food waste with vegetable waste and chicken dung was found to be promoting in pilot-scale semi-batch reactor. The effects of different substrates ratio on biogas production from food waste with vegetable waste and chicken dung and their mixture were studied under mesophilic conditions for 53 days. In the present research, about 9 day was observed as a biogas production for anaerobic co-digestion while mono digester was observed as a biogas production about 14 days. The results showed that the cumulative biogas production obtained at digester D3 (food waste: chicken dung = 1:1) were higher than that of digester D4 (food waste: chicken dung = 2:1), D5 (food waste: chicken dung = 3:1), D1(food waste: chicken dung = 1:0), and D2 (food waste: chicken dung = 0:1) by 12 %, 24 %, 45 %, and 67 %, respectively. Higher methane contents about 72 % was obtained from D3 than those from other mixtures. The adjustment of C/N ratio to optimum value as obtained in digester D3 was partly responsible for its enhanced cumulative biogas production and methane content. The research showed that anaerobic co-digestion of food waste: chicken dung = 1:1 could be the most suitable for optimum production of biogas. The data obtained from this research could be used as a basis for designing large scale anaerobic co-digestion for treatment of food waste with vegetable waste and chicken dung and their mixture. Future research is required to obtain the other inoculum in order to increasing biogas production.

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